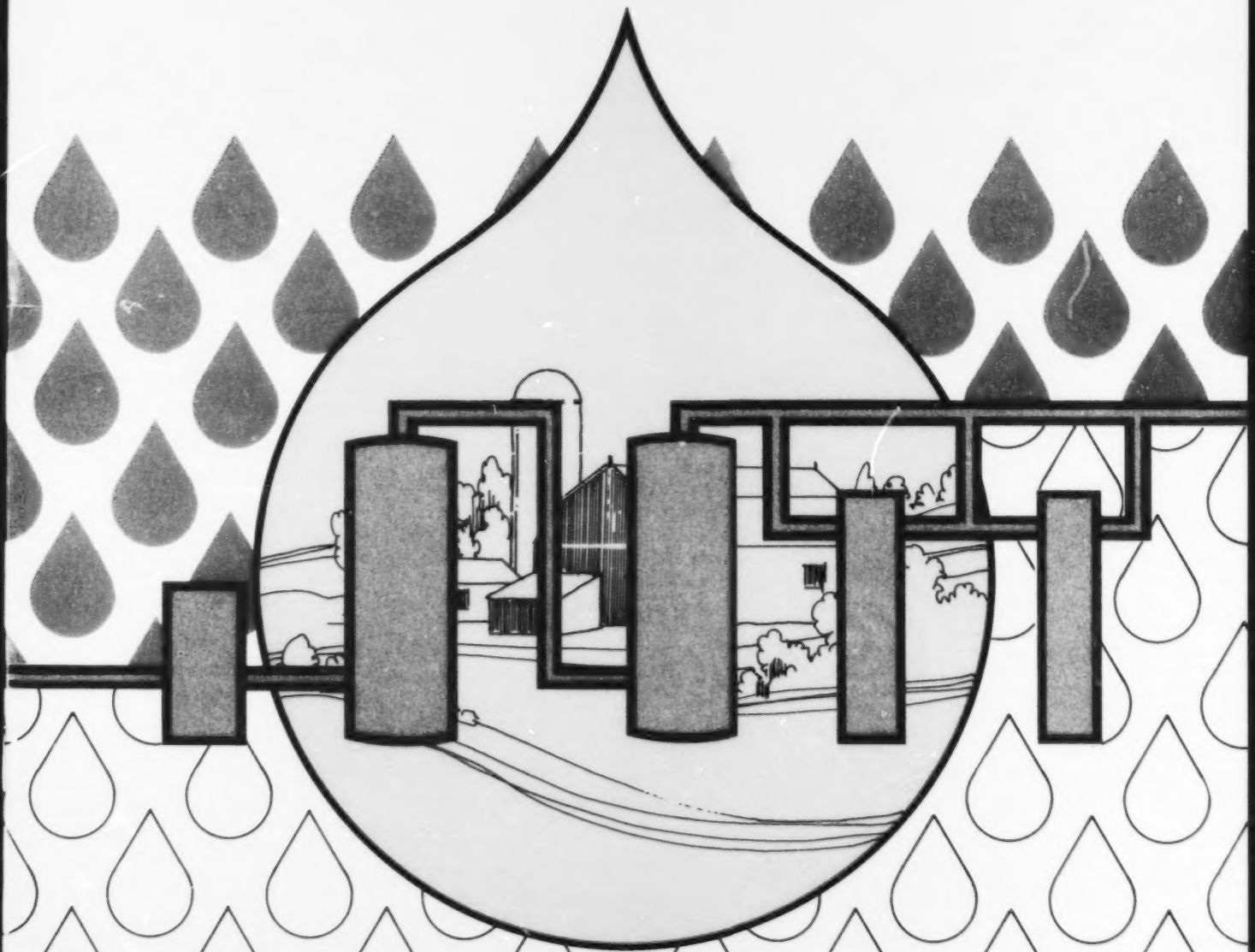
PUBLICATION 85

FARM WATER SUPPLY

Water treatment systems



Ontario

Ministry of Agriculture and Food

David Ramsay, Minister

FARM WATER SUPPLY

Water Treatment Systems

Soil and Water Management Branch

Ontario Ministry of Agriculture and Food

September 1989

ABBREVIATIONS USED IN THIS REPORT

Concentration
mg/L = milligram per litre
ug/L = microgram per litre

Temperature
°C = degree Celsius

Volume
L = litre
mL = millilitre
m^3 = cubic metre

Length
m = metre
cm = centimetre
um = micrometre
nm = nanometre

CONVERSION FACTORS

1 foot (ft)	=	0.3048 metres (m)
1 cubic foot (ft^3)	=	0.0283 cubic metres (m^3)
1 gallon (imperial gallon)	=	4.546 litres (L)
1 part per million (ppm)	=	1 milligram per litre (mg/L)
1 grain per imperial gallon (gpg)	=	14.3 milligram per litre (mg/L)
(degree Fahrenheit - 32) x 5/9	=	degree Celsius

CONTENTS

90-05299/1

Page

PREFACE 3

INTRODUCTION 4

1. Water Quality Objectives and Criteria 4
2. Surface and Groundwater Quality 4
3. Bacteriological Tests 5
4. Chemical Tests 5
5. Common Water Quality Problems 5

WATER TREATMENT 8

1. Hardness 8
   - 1.1 Water Softener 8
   - 1.2 Soluble Phosphate Additives 9
2. Iron and Iron Bacteria 9
   - 2.1 Ferrous Iron 9
     - 2.1.1 Water Softener 9
     - 2.1.2 Polyphosphates 9
     - 2.1.3 Chlorination — Filtration 9
     - 2.1.4 Oxidizing Filter 10
   - 2.2 Ferric Iron 10
     - 2.2.1 Manganese Greensand Filter 10
     - 2.2.2 Continuous Chlorination 10
   - 2.3 Iron Bacteria 10
     - 2.3.1 Shock Chlorination 10
3. Manganese 10
4. Coliform Bacteria, Protozoa, and Viruses — Disinfection 10
   - 4.1 Ceramic Filter 11
   - 4.2 Ultraviolet Irradiation 11
   - 4.3 Iodination 13
   - 4.4 Chlorination 13
   - 4.5 Ozonation 13
   - 4.6 Distillation 13
   - 4.7 Boiling 14
   - 4.8 Disinfection of Wells, Spring Boxes and Water Supply Systems 14
5. Hydrogen Sulphide and Sulphate-Reducing Bacteria 14
   - 5.1 Aeration 14
   - 5.2 Chlorination — Filtration 14
6. Chloride, Sulphate and Nitrate 14
   - 6.1 Reverse Osmosis 15
7. Turbidity 15
   - 7.1 Alum 15
   - 7.2 Filters 15

CONTENTS (cont'd)

Page

8. Gasoline and Oil 15
9. Gases (Methane) 16
10. Taste and Odor 16
    10.1 Activated Carbon Filter 16
11. Acidity 17
    11.1 Neutralizer 17
    11.2 Soda Ash 17
12. Pesticides 17
    12.1 Boiling 17
    12.2 Reverse Osmosis 17
    12.3 Activated Carbon 18

BIBLIOGRAPHY 18

APPENDICES 19

LIST OF FIGURES

Figure **Page**

1. Bacteriological Analysis of Water — Sample Submission Form 6
2. Water Softener 8
3. Chlorination-Filtration System 9
4. Disinfection Devices 12
5. Typical Low-Volume Household Reverse Osmosis Unit 15
6. Activated Carbon Devices 16
7. Neutralizer 17

LIST OF APPENDICES

Appendix **Page**

I. Water Quality Guidelines 19
II. The Influence of Water Quality on Livestock Health and Performance 21
III. Parameters to Consider in Assessing Irrigation Water Quality 22
IV. List of Contacts 23

PREFACE

This publication is intended as a guide for water treatment. It should be stressed that this guide is not intended to be used as a manual on water quality problems and treatment, since these require considerable background, training and experience. Any mention of trade names or commercial products does not constitute endorsement or recommendation for use.

This document is a revision of the Water Treatment section of the Ontario Ministry of Agriculture and Food (OMAF) Publication 476 entitled *Farm Water Supply* which was prepared by F.R. Hore in 1973. In recognition that good quality and sufficient quantity are two basic requirements of a farm water supply, it was decided that these two aspects of the original 1973 report should be highlighted in two separate publications, namely:

- Farm Water Supply — Water Supply and Distribution Systems (Publication 476); and
- Farm Water Supply — Water Treatment Systems (Publication 85).

The most noteworthy changes to the Water Treatment section of the original report, *Farm Water Supply,* are:

1. the conversion of units from imperial to metric;
2. the addition of a preface, introduction, bibliography, and four appendices; and
3. a reorganization of the subsections from a discussion of types of treatment to a discussion of water quality problems and associated treatment.

Extensive use of the Ontario Ministry of the Environment publications *Water Wells and Groundwater Supplies in Ontario* and *Information on the Use of Home Water Treatment Devices* was made in the preparation of this document.

Sam Singer, P.Eng.
Water Management Coordinator

INTRODUCTION

Water for agricultural use must not only be available in sufficient quantities, but must also be of good quality. Water quality is judged mainly by its microbiological and chemical characteristics. Clarity, freedom from taste and odor, and low temperature increase the palatability of water. In agriculture, water is used to satisfy domestic, livestock, or crop demands. Inferior water quality can put the health of the farm family and livestock at risk, and lower crop yields.

In the livestock industry, good quality water is critical for animal nutrition. Safe, palatable water can improve feed conversion and reduce illness. As a result, better water quality offers greater potential returns to the farmer in the form of healthier animals, increased milk production, and higher profits.

Good quality water is also necessary for cleaning and sanitation purposes. On dairy farms, soft water is more effective for cleaning udders, components of milking systems and handling equipment than hard water. Hard water tends to combine with the nutrients from milk to form "waterstone," a film that provides a potential site for bacterial growth.

Water is a major constituent (90-98%) of a crop. For crops that are to be eaten raw, or with little processing, water must be of the best microbiological quality possible. Dissolved minerals in water can provide needed nutrients, but if found at levels that are too high, they can reduce plant vigor. Suspended particulates in water can also wear or clog irrigation equipment and leave a residue on foliage.

1. WATER QUALITY OBJECTIVES AND CRITERIA

The quality of water required on the farm is dependent on its intended use. These uses are commonly classed as domestic, livestock, and irrigation.

Water used for drinking and other household purposes should meet the Ontario Drinking Water Objectives (see Appendix I). These objectives were developed by the Ontario Ministry of the Environment to address the chemical, physical, microbiological, and radiological aspects of drinking water quality. Water used in the handling of produce and milk should also meet the Ontario Drinking Water Objectives.

Guidelines have been developed for water provided to livestock (see Appendix I and II). The sensitivity of an animal which is being exposed to a substance will depend on the species, age, and its physiological condition. The amount of a substance that can be present in water without harming livestock will depend on the total intake of that substance in both the water and feed. There may be situations, however, where water of a different quality than that suggested in the guidelines may be used. In such cases, advice from the OMAF animal industry specialist should be sought.

In addition to the direct effects on livestock, certain substances in water may contaminate animal products, making them unfit for marketing.

The suitability of water for irrigation cannot be precisely defined because there are many factors to consider. These include soil and crop types, climatic conditions, and irrigation practices. Total salt content and the predominance of sodium in the water are important criteria for evaluating irrigation water quality.

In general, soils with poor drainage characteristics require water of higher quality than better drained soils. Guidelines for irrigation water quality are shown in Appendix I and III.

2. SURFACE AND GROUNDWATER QUALITY

In Ontario, it is estimated that about 90% of farms make use of groundwater for household purposes and about 80% make use of it for livestock watering. Crop water needs are met by precipitation for the most part and where economical, are supplemented by irrigation from surface or groundwater supplies.

Surface water sources include streams, lakes and farm ponds. Because runoff can directly enter these water sources they are particularly susceptible to contamination. Common contaminants include sediment, manure, milkhouse and septic tank wastes, and agricultural chemicals. Surface water sources should be considered for household use only as a last resort because it is difficult and expensive to make these supplies safe.

If a surface water source is to be used to supply water, then there are certain precautions which should be taken. Generally, these precautions try to isolate the water source from sources of contamination. Farm ponds should be protected from surface runoff of fields that have been treated with pesticides, fertilizers, or manure. Berms and ditches may be used to divert the runoff away from or around the surface water supply. Having a grassed buffer strip between the pond and the treated area helps to act as a filter, which reduces the risk of contamination. When spraying pesticides close to surface water, a buffer strip 5 to 10 m wide should be left between the water source and the sprayed areas to avoid contamination.

In addition, nutrient management practices that reduce the amount of fertilizer left on the surface exposed to erosion or washoff can reduce the likelihood of contamination. Care should be taken to control the runoff from barnyards and manure storage areas in a safe and responsible manner. Restricting the access of livestock to streams will also reduce possible contamination of the water supply.

Measures which control soil erosion will also reduce the movement of sediment and contaminants that are attached to the sediment.

Groundwater is often preferred over surface water for the following reasons:

1. minimum treatment is required;
2. long, costly pipelines are not needed;
3. temperature and quality are usually more acceptable and uniform throughout the year; and
4. with proper management the supply is more dependable, having proven quantities and quality.

Groundwater will naturally contain minerals of varying kinds and amounts, depending on the exposure of the water to various soluble compounds as it flows beneath the earth's surface. Harmless minerals in moderate amounts give water a pleasant taste. However, some minerals may be present in excessive quantities and can make the water unfit for use.

Groundwater may become contaminated in many ways, for example, seepage from septic tanks, barnyards, and manure storage areas, or by direct entry of contaminants into the wellhead. A properly located and constructed

well will reduce the risk of contamination from these sources.

To reduce the risk of contamination, a well should be located upslope and as far away as possible from potential sources of pollution. A dug well, or a drilled well with partial depth casing, should be at least 30 m away from any potential pollution source. Drilled wells with a full depth, water tight casing should be located at least 15 m away from pollution sources. A well should be located at a higher elevation than that of the immediately surrounding area to prevent surface water, which may be polluted, from ponding near the well and infiltrating into it.

During well construction or repair, a well and the groundwater around it may become contaminated. Therefore, the well water should be tested and if necessary, the well should be disinfected to ensure that it is bacteriologically safe.

3. BACTERIOLOGICAL TESTS

Drinking water is tested for the presence of total coliform and fecal coliform bacteria. Total coliforms are found in animal wastes, sewage, soil, and on vegetation, whereas, fecal coliforms are found in the intestines of warm-blooded animals. Fecal coliforms tend to die rapidly outside the body, therefore, their presence in water indicates a relatively recent contamination.

The presence of fecal coliform bacteria is representative of sewage contamination and is of greater concern because the risk of disease-causing agents also being present in the water is higher. Water containing fecal coliform bacteria is considered unsafe for human consumption.

Bacteriological analyses show the condition of a water supply only at the time the sample was collected. If it is suspected that a water supply is being contaminated, it is recommended that three samples be taken one to three weeks apart. If the results indicate a bacteriologically safe supply, it need only be tested once or twice a year thereafter. If the water is found to be contaminated, it will have to be disinfected.

Additional samples should be taken:

- when there has been a change in the condition of the supply, such as flooding after a heavy rainfall;
- following periods when the well has not been in use;
- after repairs are made to a well; or
- if there is a change in the taste, odor, or appearance of the water.

A free bacteriological testing service is conducted by the Ontario Ministry of Health laboratories (see Appendix IV). Sterile sample bottles and instructions for the collection of water samples can be obtained from the local Health Unit or Medical Officer of Health. The instructions should be followed very carefully and the samples should reach the nearest laboratory within 48 hours of the time they are taken.

Figure 1 shows the form that is used to submit a bacteriological sample. It should be noted that the results provided by bacteriological tests do not imply anything about the chemical quality of the water, which is also important to health.

4. CHEMICAL TESTS

In order to determine the chemical quality of a well water supply, a chemical analysis should be taken upon completion of the well and again 30-60 days after it has been in use. Samples should be taken from a faucet outlet between the pump and any water treatment unit or water storage tank after the water has been allowed to run for at least five minutes. The sample should be collected in a clean container and should be at least 0.5 L to 1.0 L in volume to provide the laboratory with a sufficient sample for analyses. Chemical samples can be submitted to any commercial laboratory or water conditioning company. Discussions with your neighbors and the following description of common water quality problems can assist you in deciding which parameters you may want tested.

5. COMMON WATER QUALITY PROBLEMS

The common water quality problems may be related to health considerations, disagreeable tastes and odors, the failure of plumbing equipment or the staining of fixtures. A summary of the common water quality problems, probable causes and possible corrective measures is given in Table 1.

Ontario

Ministry of Health / Ministère de la Santé — Laboratory Services Branch / Service de Laboratoire

Date Received/ Date Reçue	Lab No./ No. du Lab.

Bacteriological Analysis of Water/ Analyse Bactériologique de l'eau

Sample taken by/ Echantillon prélevé par	Location of supply (Lot, Con., Twp.)/ Lieu de Prélèvement (Lot, Concession, Commune)	County	Date collected/ Date du Prélèvement

Your name and return address must appear on all copies / Votre nom et votre adresse de retour doivent paraître sur toutes les copies.

Name/Nom	
Street, R.R., Box No./Rue, R.R., Casier Postal	
City, Town/Ville	
Province	Postal Code/Code Postal

☐ **Private Citizens:** check this box. Drinking water only. See reverse of report for interpretation.
Particuliers: cocher cette case. Eau potable seulement. Voir au verso pour interprétation.

Consult your local health unit for further information /Pour les directives additionel consultez votre unité sanitaire local.

FOLD

SHADED AREAS FOR OFFICIAL AGENCIES ONLY
ZONE OMBRÉE RÉSERVÉE AUX AGENTS OFFICIELS

Non potable samples MUST be received within 6 hours if unrefrigerated or within 24 hours if refrigerated

FOLD

CHECK APPROPRIATE BOXES / COCHER TOUTES LES CASES APPROPRIÉES

DRINKING WATER	NON-DRINKING WATER	COMMENTS
☐ Treated ☐ Non-treated	☐ Recreational ☐ Swimming Pool	
☐ Municipal	☐ Hydrotherapy Spa ☐ Sewage	
☐ Other Public	☐ Other	
☐ Single Household		

BACTERIAL COUNT / NUMERATION DES BACTÉRIES
Based on 100 ml volume / Base sur un volume de 100 ml

Total Coliform/ Totale des colibacilles	Faecal Coliform/ Colibacilles Fecaux	Faecal Strep / Streptocoques Fecaux	BACTERIAL COUNT Based on 1.0 ml volume: APC
Background	Paeruginoss	S. aureus	

Technician	Checked by	Date

Figure 1. Bacteriological Analysis of Water — Sample Submission Form

TABLE 1. COMMON WATER QUALITY PROBLEMS

PROBLEM	PROBABLE CAUSE	CORRECTIVE MEASURES
Mineral scale build-up in kettles, water heaters and plumbing. Soap scum. Excess soap consumption. Dingy laundry. Bathtub ring.	Hardness (hard water)	1. Water softener 2. Soluble phosphate additives
Rusty to black stains on fixtures and laundry. Rusty to black colored water. Metallic taste.	Iron and manganese	1. Water softener 2. Polyphosphates 3. Chlorination-filtration 4. Oxidizing filter 5. Manganese greensand filter 6. Continuous chlorination
Red to brown slime in toilet tanks and plumbing. Reddish filament-like particles in water. Reduced well yield. Sudden appearance of iron staining. Unpleasant taste or odors.	Iron bacteria	1. Shock chlorination
Gastrointestinal disease, including typhoid fever, dysentery, and diarrhea.	Coliform bacteria, protozoa and viruses	1. Ceramic filter 2. Ultraviolet irradiation 3. Iodination 4. Chlorination 5. Ozonation 6. Distillation 7. Boiling
"Rotten-egg" odor and taste. Tarnished silver and copper. Corroded plumbing.	Hydrogen sulphide and sulphate-reducing bacteria	1. Aeration 2. Chlorination-filtration
Salty taste. Corroded plumbing.	Chloride	1. Reverse-osmosis
Water has laxative effects.	Sulphate	1. Reverse-osmosis
No obvious symptoms in adults but may cause a condition in infants called methemoglobinemia (child becomes listless and the skin takes on a blue color).	Nitrate	1. Reverse-osmosis
Cloudy water.	Turbidity (clay)	1. Alum treatment 2. Filters
Petroleum odor or film on water.	Gasoline and oil	1. Activated carbon filter
Gassy odor. Gas bubbles escaping from water.	Gases (methane)	1. Aeration 2. Activated carbon filter
Objectionable taste and odor.	Chlorine, decayed organic matter	1. Activated carbon filter
Corrosion of steel and copper pipes. Stains on porcelain.	Acidity	1. Neutralizer 2. Soda ash
Nausea.	Pesticides	1. Boiling 2. Reverse osmosis 3. Activated carbon

Sources: Cole, 1985.
Funk et al., 1980.
Ontario Ministry of the Environment, Information on the Use of Home Water Treatment Devices.
Rozelle, 1985.

The treatment of water at the point-of-use or point-of-entry is an effective and economical method to remove undesirable contaminants. Alternatives to point-of-use treatment include drilling a new well, hooking up to an existing community water treatment system, or using bottled water. These alternatives tend to be expensive and sometimes inconvenient. This section briefly describes water quality problems and outlines the various treatment methods which can be employed on the farm to resolve them.

1. HARDNESS

Hardness, or "hard water" as it is frequently called, is a common characteristic of groundwater in most areas of southern Ontario. Groundwater as it moves through limestone bedrock or carbonate-rich overburden dissolves calcium and magnesium compounds which cause hardness. Hardness is expressed as mg/L equivalent of calcium carbonate ($CaCO_3$). Water containing 0-50 mg/L of hardness is considered soft, 50-100 mg/L is moderately soft, 100-200 mg/L is moderately hard, 200-400 mg/L is hard, and 400-600 mg/L is very hard.

A high level of water hardness is a nuisance which results in scale formation on kettles, prevents soap from lathering, and can cause a dingy appearance to laundry. Two common water treatment processes exist which can be used as corrective measures; these are water softeners and soluble phosphate additives.

1.1 Water Softener

A water softener consists of a tank which contains a synthetic zeolite (Figure 2). As hard water passes through the softener, sodium from the zeolite is exchanged with the calcium and magnesium which is present in the water. Thus the water emerging from a softener contains sodium salts instead of calcium and magnesium salts. Because zeolite has a limited exchange capacity, it is necessary to regenerate the zeolite periodically with a solution of common salt (sodium chloride). During regeneration, the calcium and magnesium salts are released from the zeolite and, along with the excess common salt, are flushed out of the softener. If the regeneration water is released into a septic system, the system will be able to handle the volume of water, but the salt may cause the underlying soil to clog, thereby possibly reducing the efficiency of the system.

Some softeners are regenerated automatically and require only the periodic addition of salt. A separate tank is required to hold the salt supply, which will normally last for several months. Some softeners are semi-automatic, while others are operated manually and require the addition of the correct amount of salt with each regeneration. The capacity of a softener is rated on its exchange capacity in grains of hardness that can be removed between regenerations, and on the maximum flow rate through the unit. Exchange capacities of softeners range from 20,000 grains to over 100,000 grains. To conserve soft water and lengthen the time between regenerations, the softener may be connected only to the hot water supply and other faucets where soft cold water is desired.

Soft water can be obtained on the farm by purchasing and installing a large, medium, or small capacity, automatic, semi-automatic, or manually operated softener. Rental services for softeners are also widely available throughout the province. It is up to the individual to decide whether the conveniences of the rental service or automatic operation are worth the added expense. Softeners range in price from $500 to $2,700 for the larger and more sophisticated models (1986 prices).

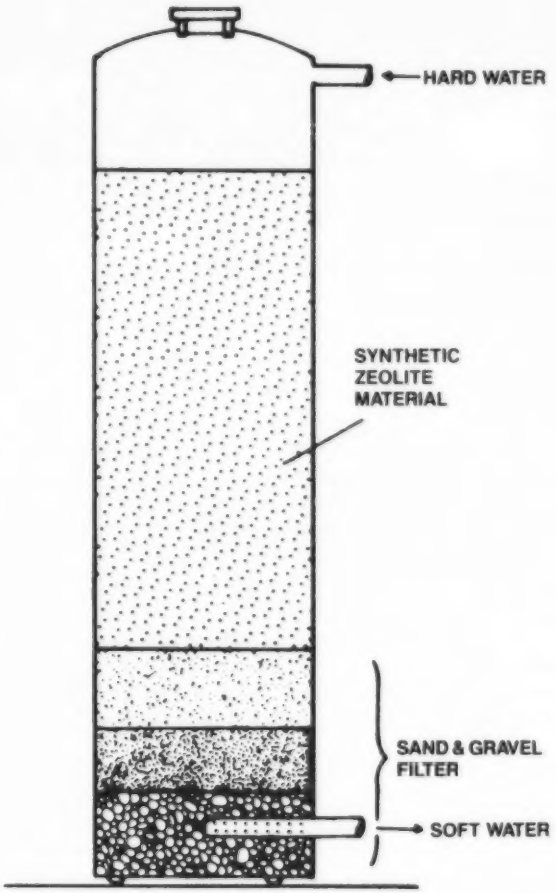


Figure 2. Water Softener

When choosing the capacity of a manual or semi-automatic softener, it is advisable to select a large enough softener that regeneration will not be required more frequently than once every two or three weeks. A small capacity softener could cause dissatisfaction because the high frequency of regeneration required can become a tedious chore. Once a regeneration period is decided upon, the capacity required depends on the hardness of the water and the quantity of water used. Softener manufacturers are equipped to test the hardness of the water and will help to select the size and type of softener to install. As a general rule, water containing less than 5 grains/gallon or 72 mg/L $CaCO_3$ of hardness does not require softening.

Water softeners increase the sodium content of water.

Therefore, individuals on a low sodium diet or those suffering from high blood pressure or heart disease should consult their physician before drinking softened water.

1.2 Soluble Phosphate Additives

Soluble phosphate additives are available for water softening. These softeners are added to hard water to prevent it from reacting with soap or detergent to form a scum. However, these additives do not remove the carbonates in the water, but rather keep them in solution and therefore a mineral scale will still form in kettles, water heaters and plumbing.

2. IRON AND IRON BACTERIA

Iron in a water supply exists in several forms, such as ferrous iron, ferric iron, and iron bacteria. When iron is present in a water supply in excess of 0.3 mg/L, it gives water a bitter metallic taste, and may cause brown/red stains on fixtures, or brown spots on laundered clothing. The water may also turn brown when heated.

The type of iron present in a water supply can be determined by the appearance of the water as it is drawn from the faucet. Ferrous iron is present if the water from the faucet looks clear and colorless, but particles appear in the solution when allowed to stand for a few minutes. Ferric iron is present when the water from the faucet appears rusty or has a red or yellow color. If a gelatinous sludge is present in the water tank, this would indicate that iron bacteria are present.

The methods to reduce iron vary with the type of iron present in the water supply.

2.1 Ferrous Iron

Ferrous or dissolved iron is usually found in groundwater supplies which have not been exposed to oxygen. This form of iron is colorless. The treatment of ferrous iron depends on its concentration in water. For ferrous iron concentrations in water of less than 5 mg/L, a water softener or polyphosphates can be used. Where the ferrous iron concentration is in the range of 5 to 10 mg/L, two treatment methods are available: chlorination-filtration, and oxidizing filters.

2.1.1 *Water Softener*

Most synthetic zeolite softeners have a limited capacity to remove ferrous iron by exchange with sodium in the same manner as calcium and magnesium. It is important to note that a softener exchanges only the dissolved or ferrous form of iron; the oxidized ferric form will only foul the unit. If iron has been oxidized before softening by exposure to air or chlorine, a sand filter should be placed in front of the softener to protect it. The pH of the water supply should be maintained at a minimum of 6.7 for efficient operation.

2.1.2 *Polyphosphates*

Polyphosphates are chemicals which surround the ferrous iron and keep it in solution. This prevents the oxidation and precipitation of iron and thus keeps the water clean. Since polyphosphates do not actually remove the iron from the water, the water will retain its metallic taste. One disadvantage of polyphosphates is that their effectiveness may be reduced when water is heated.

2.1.3 *Chlorination-Filtration*

The chlorination-filtration treatment involves the chlorination of the water by means of a chlorinator unit to oxidize and precipitate the iron followed by filtration with a sediment filter to remove the iron precipitate (Figure 3). In many cases, water containing iron is acidic and must have its pH raised above 7.0 for effective removal of iron using this treatment process. Soda ash (an alkali solution) can be used for this purpose and can readily be added to the water by means of the same chemical feeder that adds the chlorine.

After chlorine has been added, the oxidation process

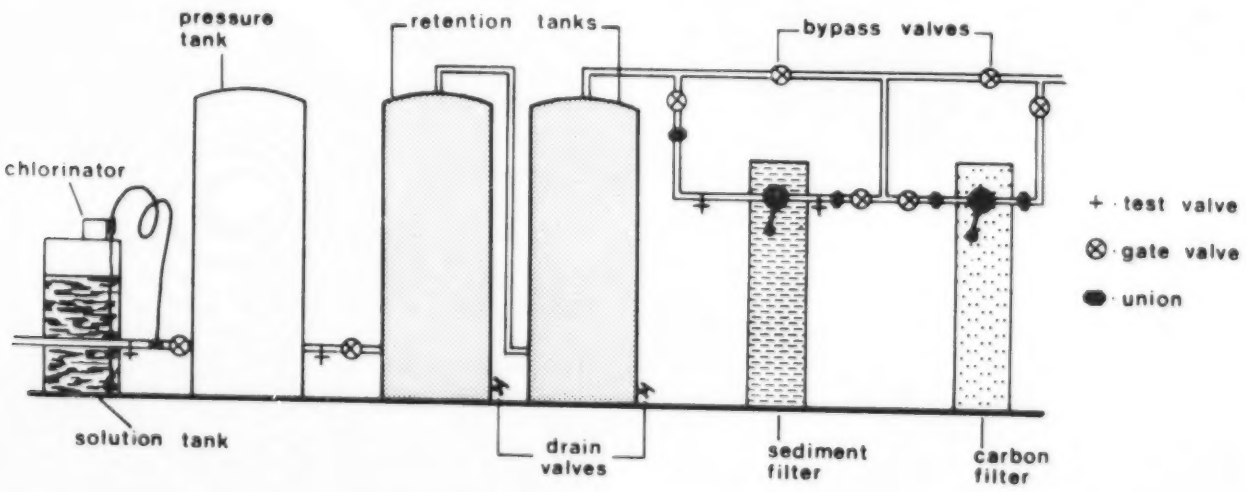


Figure 3. Chlorination-Filtration System

takes about 20 minutes. A farm water system which produces 15-20 L/min. will require at least two 160 L retention tanks to provide sufficient time for oxidation and settling. A sediment faucet is placed at the lowest fitting on each tank so that the settled iron can be flushed out. After the water leaves the retention tanks, it enters the sediment filter where the unsettled iron particles are filtered out. A chlorine residual of about 1 mg/L and a pH of 7 to 8.5 is recommended before the water moves to the activated carbon filter. These levels can be tested at a sampling valve installed between the sediment filter and the activated carbon filter. The water then goes to an activated carbon filter which removes the excess chlorine. In cases where iron bacteria are also present in the water supply, the addition of chlorine will control their growth in the water system.

2.1.4 *Oxidizing Filter*

An oxidizing filter with a filtering medium that has been treated with manganous sulfate and potassium permanganate can be used to treat water with ferrous iron. The filtering medium changes the ferrous form of iron to the ferric form which can then be removed by filtration. It is important that the pH of the water be well above 7.5 to promote better flocculation and filtration.

2.2 Ferric Iron

Ferrous iron will convert to ferric iron when exposed to oxygen (air), an oxidant such as chlorine, or heat. Water containing ferric iron appears colored or cloudy. However, when the water is allowed to stand for a few minutes, the particulate iron settles to the bottom. When this occurs, there are several methods to remove the particulate iron, such as a manganese greensand filter and continuous chlorination followed by an oxidizing filter.

2.2.1 *Manganese Greensand Filter*

If the ferric iron content is below 10 mg/L, then a manganese greensand filter can be used. This will remove both the precipitated iron and also any iron that is still in solution. The filter must be backwashed regularly and the oxygen supply regenerated in order to ensure its effectiveness on a regular basis. This is achieved by flushing the filter with a large volume of water and then rinsing with a solution of potassium permanganate. It is important that the pH is above 7.0. The presence of iron bacteria in the water can cause a slime build-up on the filter and thereby reduce its effectiveness. It may be necessary to chlorinate the water before it enters the filter to ensure that the bacteria are destroyed. A manganese greensand unit ranges in price from $370 to $1,250 (1986 prices).

2.2.2 *Continuous Chlorination*

When the concentration of ferric iron is greater than 10 mg/L, continuous chlorination followed by an oxidizing filter can be used.

2.3 Iron Bacteria

The presence of iron bacteria is identified by a gelatinous sludge in the water supply system. Although these bacteria do not present a health hazard, they can clog pipes and valves and make the water unpalatable. In a well, iron bacteria will coat the inside of the well casing, water piping, and equipment, and may thereby reduce well yield, restricting the flow of water. Iron bacteria also creates an environment which encourages the growth of sulphate-reducing bacteria which cause a "rotten egg" odor in water. Shock chlorination followed by continuous chlorination is one way to remove iron bacteria.

2.3.1 *Shock Chlorination*

Shock chlorination is a procedure for disinfecting a well with a large volume of superchlorinated water. To be effective, the entire well depth, the formation around the bottom of the well, the pressure system and the distribution system should be disinfected. Shock chlorination of the complete water supply system is recommended to remove iron bacteria prior to the installation of any water conditioning equipment. After the system has been treated, a continuous feed of chlorine solution should be injected ahead of the system pressure tank which is followed by an activated carbon media-type filter.

This procedure will not eliminate iron bacteria from the water system, but rather keep it under control. Shock chlorination must be repeated each spring and fall in order to control the iron bacteria. Wells which have never been shock chlorinated or have not been shock chlorinated for some time will require two or three shock chlorination treatments to make a significant improvement in water quality.

3. MANGANESE

The presence of manganese in water supplies is objectionable because it stains laundry, and at excessive concentrations causes undesirable tastes. Manganese concentrations in excess of 0.05 mg/L in drinking water will produce an objectionable taste. Manganese may also encourage the build-up of slimy coatings in piping which can slough off as black precipitates.

Manganese usually appears more readily in water containing iron, therefore the same methods employed to reduce iron can be used to remove manganese (see Iron).

4. COLIFORM BACTERIA, PROTOZOA, AND VIRUSES — DISINFECTION

Water free from disease-causing bacteria, protozoa and viruses is essential for drinking purposes. Groundwater generally does not contain these microorganisms unless it has been polluted by surface water or seepage from septic tanks, privies, cesspools or barnyards. Well contractors are required to seal the upper part of a well to prevent these sources of pollutants from entering the well.

The microbiological quality of drinking water has traditionally been viewed as the most important aspect of drinking water because of its association with waterborne diseases (ie. typhoid fever, cholera, enterovirus disease, bacillary and amoebic dysenteries, and many varieties of gastrointestinal disease). Pathogens, which are disease-causing microorganisms, are usually greatly outnumbered in water by normal intestinal bacteria. Because the normal intestinal bacteria are easier to isolate and identify, their presence in a water sample indicates that pathogens could be present.

There are three tests which are commonly used to determine bacteria densities in water. They are the Most Probable Number (MPN) test, the Membrane Filter (MF) test, and the Presence-Absence (P-A) test. When the MPN

or MF tests are used, the Ontario Drinking Water Objectives state that total coliform bacteria should not be present in densities of 5 or more organisms/100 mL water. When the P-A test is used, total coliforms should not be found within 48 hours. Fecal coliforms should not be detected in any sample taken for any of the above tests. Although virus detection methodology has improved greatly in recent years, no virus limit is outlined in the Drinking Water Objectives at this time.

With respect to drinking water, the most important protozoan parasites are *Entamoeba hystolitica,* which causes amoebic dysentery and hepatitis, and *Giardia lamblia,* which can be responsible for gastrointestinal disturbances, flatulence, diarrhea, and discomfort. Adequate treatment of raw water and proper maintenance of the water supply system appear to provide the best protection against these organisms.

The treatment of a water supply for the purpose of destroying bacteria, viruses, and protozoa is known as disinfection. Seven possible methods for disinfecting water are available. These include ceramic filters, ultraviolet irradiation, iodination, chlorination, ozonation, distillation, and boiling (Figure 4). The following discussion on these methods and their limitations is based on the Ontario Ministry of the Environment publication entitled *Information on the Use of Home Water Treatment Devices.* To disinfect a well or spring box, shock chlorination can be used.

4.1 Ceramic Filter

Raw water may be treated with a ceramic filter (Figure 4A). However, there are certain conditions which make treatment by filtration alone impractical. The following raw water quality characteristics should be carefully investigated when considering the use of a ceramic filter:

1. Bacterial levels should not be excessive. As a guideline, raw water should not contain more than 1,000 total coliforms/100 mL, or more than 100 fecal coliforms/100 mL.
2. Raw water in which human pathogenic viruses are known to be present should not be treated by this process. Raw water which meets the guideline for coliform levels would not normally be expected to present a virus problem.
3. Ceramic filters do not provide complete protection against the build-up of microorganisms in the distribution system. Initially, and after a period of non-use, disinfection of the plumbing system downstream of the filter is recommended prior to putting it into operation. This procedure is not required for counter-top or under the sink line by-pass units.

In order to ensure the proper functioning of a ceramic filter, care should be exercised when handling, transporting, installing and cleaning a filter unit.

To be effective, filtration devices impregnated with silver should not release silver, or any other chemicals, in amounts that exceed the Ontario Drinking Water Objectives. Ingestion of excessive amounts of silver may result in argyria, a condition characterized by a blue-gray discoloration of the skin, eyes, and mucous membranes. The exact quantity of silver required to produce argyria is unknown, but it is believed to be in the order of 1,000 mg. The maximum acceptable concentration of silver, 0.05 mg/L, therefore incorporates a substantial margin of safety.

4.2 Ultraviolet Irradiation

Contaminated water can also be treated by passing it over an ultraviolet tube (Figure 4B). The rays emitted by the tube will kill bacteria provided that there is sufficient contact time. If the water is colored or turbid, the efficiency of this system will be reduced. In addition, disinfection of the distribution system is recommended after any period of non-use.

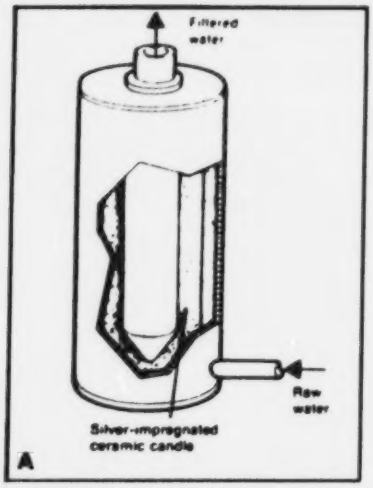
The raw water which enters the ultraviolet unit should be of satisfactory quality to ensure adequate treatment. The following raw water constituents may render the unit ineffective:

1. Raw water containing greater than 1,000 total coliforms/100 mL, or greater than 100 fecal coliforms/100 mL, should not be treated by this device.
2. Protozoan parasites such as *Giardia lamblia* and *Entamoeba hystolitica* may require the use of a filter with a pore size equal to, or less than, 5 micrometres.
3. Treatment of excessive color, turbidity, iron, or organic impurities may require appropriate auxiliary equipment.

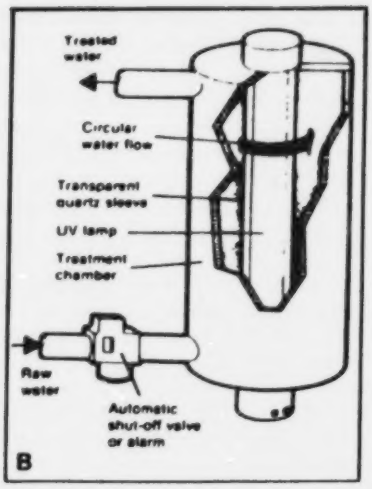
Bacterial analyses of the treated water should be made with sufficient frequency to demonstrate the efficacy of the device in use. To be effective, the operation of the unit should satisfy the following criteria:

1. The unit must provide a minimum dose of 16,000 microwatt/second/cm^2 at a wavelength of 253.7 nanometres (nm) at maximum flow. If the dosage is marginal, the bacteria which are killed by the ultraviolet are susceptible to reactivation by exposure for only a moment to visible light. As much as two-thirds of the pathogenic bacteria recently killed by ultraviolet can be brought back to life when filling a pitcher of water for storage in the refrigerator.
2. The unit should incorporate a device for monitoring or sensing ultraviolet transmission through the maximum depth of water in the chamber to effectively meet the microbiological criteria in the Drinking Water Objectives mentioned above. The monitoring or sensing device shall be designed to trigger an alarm in the event of lamp or sensor failure, or if insufficient ultraviolet light reaches the sensor.
3. The unit should have an automatic flow control device which is accurate within the expected range of operating pressures so that the maximum design flow rate of the unit is not exceeded.
4. The device should be designed to permit frequent mechanical or chemical cleaning of the water-contact surface of the jacket or lamp, without impairing the potability of the water.
5. The construction materials should not react with water, nor impart toxic constituents to it as a result of physical or chemical changes caused by exposure to ultraviolet energy.
6. The unit shall be designed to protect the operator against electrical shock or excessive ultraviolet energy.

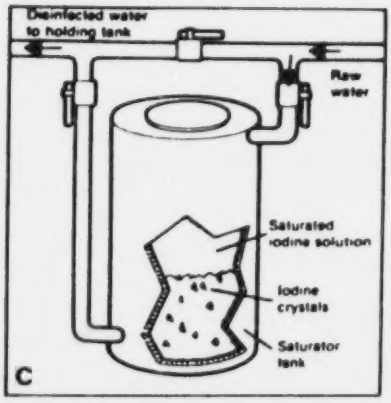
It should be noted that the output of an ultraviolet device decreases with age, so the lamp should be changed as required. Ultraviolet devices range in price from $200 to



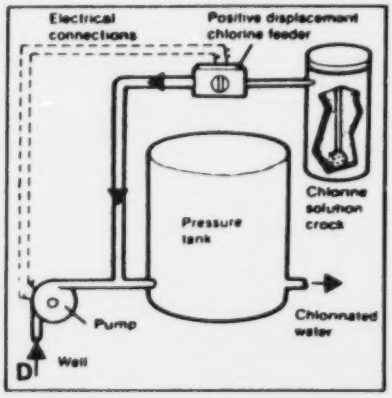
A silver-impregnated ceramic filter cartridge



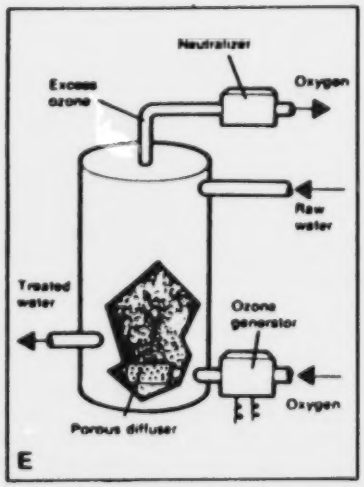
A typical UV irradiation device



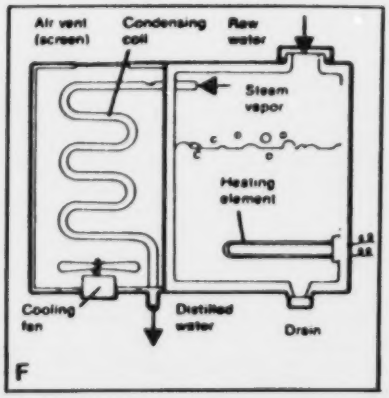
Typical (saturator type) iodine feeder



A typical hypochlorination system



An ozonation device for home water treatment



A typical steam distillation unit

Figure 4. Disinfection Devices

$2,000 (1986 prices). The replacement lamp is approximately $90 to $150 (1986 prices).

4.3 Iodination

An iodinator can be used for disinfecting water supplies (Figure 4C). The raw water fed into the unit should be of satisfactory quality to ensure adequate treatment. The same three raw water considerations for ultraviolet irradiation apply to iodination. Another limitation is that the rate of disinfection may be slower at low temperatures; therefore, a contact time of 30 minutes is required, particularly in near-freezing water. In addition, an appropriate activated carbon filter positioned after the iodinator's retention tank may be advisable when the unit is used year-round because of the possible adverse effects of iodine on thyroid metabolism.

To be effective, the operation of the unit should satisfy the following criteria:

1. The iodinator should be capable of providing a dosage of iodine that will produce a continuous iodine residual of between 0.5 and 1.0 mg/L following a contact time of 15 minutes for well waters, and 30 minutes for surface waters. A retention tank, in addition to a conventional pressure tank, may be required to achieve proper contact time.
2. The construction materials of both iodinators and contact systems should not react with water or with iodine, nor impart toxic constituents to treated water.
3. If a saturator is used, the unit should be so designed as to permit an easy means of checking the level of iodine crystals. If other types of iodine-releasing devices are used, frequent measurement of the iodine residual is required.
4. An iodine residual test kit with a range of 0.5 to 1.0 mg/L should be available for the user to carry out periodic tests for the desired residual levels.

4.4 Chlorination

Chlorinator units feed a weak solution of chlorine in the form of sodium hypochlorite into the water distribution system immediately after it comes from the well (Figure 4D). This process is known as hypochlorination. To ensure that existing organisms are destroyed, the chlorine must be in contact with water for 20 minutes before the water can be used. After a 20 minute contact period, some residual chlorine in the water is desirable to ensure that the water is safe. A free-available chlorine residual of at least 0.5 mg/L is usually satisfactory. Chlorine residual test kits capable of detecting free-available chlorine within a range of 0.1 to 1.5 mg/L are available for the user to periodically test for the desired residual level. In order to achieve the proper contact time, a retention tank may be required in addition to a conventional pressure tank.

Small chlorinator units (chemical feeders) which automatically feed a chlorine solution into the water are available commercially. The chlorinator is installed in conjunction with the pressure system; when the water pump is in operation, the chlorinator draws the chlorine solution from a chlorine-resistant container and feeds a controlled amount into the water. Although the operation is entirely automatic, a constant supply of chlorine solution in the container is necessary and regular checks on its operation are advisable. To be effective, the construction materials of both the chlorinator and contact system should not react with water or with chlorine, nor impart toxic constituents to the treated water.

Providing safe water by simply adding a chlorinator unit to a conventional pressure system is a recognized problem; in many cases the chlorine is not in contact with the water for the 20 minutes necessary to destroy harmful organisms before it is used. Hence, a different method of chlorination called superchlorination is recommended.

Superchlorination involves the addition of a greater quantity of chlorine which considerably reduces the contact time required to kill organisms. Superchlorination, as the name implies, leaves a high chlorine residual in the water which imparts an objectionable chlorine taste and odor. This water can be used for all purposes in the home or barn. For drinking or cooking purposes, however, where palatability is a factor, the water should be dechlorinated by passing it through an activated carbon filter. The amount of chlorine used in disinfection and the residual left after superchlorination is not considered to be at toxic levels. The concern with a high residual is one of taste and odor.

The same three raw water considerations for ultraviolet irradiation apply to chlorination. With chlorination, excessive dissolved iron, manganese, or some organics may precipitate, thereby requiring post-filtration treatment. If an activated carbon filter is used, a tap should be installed before the filter to permit testing for the proper chlorine residual levels.

4.5 Ozonation

Ozonation is another method by which water can be disinfected (Figure 4E). This method is used extensively in municipal systems in Europe and is slowly gaining popularity in the United States and Canada. Ozone has not been used in household applications, but some attempts are being made to introduce it. To be effective, the operation of the unit should satisfy the following criteria:

1. After a contact time of at least five minutes, the device should provide a free-residual ozone of 0.5 mg/L immediately after treatment. An ozone specific residual test kit with a range of 0.1 to 1.5 mg/L ozone should be provided with the unit, to enable the user to periodically test for the desired residual levels.
2. Excess unused ozone from the treatment compartment should not be released into the immediate environment.
3. The construction materials of ozonators and contact systems should not react with water, ozone, or ozonated water, nor impart toxic constituents to the treated water.
4. The device should be constructed in such a manner as to avoid any electrical hazards to the user.

The same three raw water considerations for ultraviolet irradiation apply to ozonation. Excessive dissolved iron, manganese or some organics may precipitate, thereby requiring post-filtration treatment. After a period of non-use, the system should be disinfected prior to putting it back into operation with the ozonation device.

4.6 Distillation

Distillation involves the heating of raw water and the condensation of the vapor to produce distilled water (Figure 4F). Distillation units range in price from $475 to $18,000

(1986 prices). Although it is an expensive process yielding small quantities of treated water, it is included as another possible method for disinfection. To be effective, the construction materials of the unit should not react with the water to be treated, nor impart toxic constituents to the distilled water. The device should be constructed in such a manner as to avoid any electrical or fire hazards to the user.

The following are three limitations to this type of treatment:

1. It should be recognized that during the process of distillation any steam volatile organics in the input water (eg., phenolics) may be carried over and concentrated in the condensate. Claims for the removal of chloroform, pesticides, herbicides, or other organics should be backed by adequate test data.
2. Microbial recontamination of the distilled water in the reservoir with undesirable microorganisms such as *Pseudomonas* may be a problem unless the reservoir is effectively washed and cleaned regularly.
3. Distilled water should be stored in non-metallic containers, or in receptacles specifically designed for distilled water. If a metallic container is used, the metal tends to leach into the water.

4.7 Boiling

Small quantities of water can be disinfected by boiling vigorously for three minutes. After boiling, the water should be cooled in a clean, covered receptacle. The flat taste of boiled water can be eliminated by aeration. This can be done by pouring the water from one vessel to another several times, or by vigorous stirring. For larger quantities of water, chlorination is cheaper and more convenient.

4.8 Disinfection of Wells, Spring Boxes, and Water Supply Systems

New or repaired wells and spring boxes should be disinfected thoroughly because they may be contaminated from the equipment, material, or surface water that may be introduced. This can be done through shock chlorination. It is also recommended that the complete water supply system be disinfected at the same time.

To disinfect a well, an estimate of the number of litres of water in the well should first be made. For every 450 L of water, 0.5 L of household laundry bleach should be mixed with 25 L of water to make a strong chlorine solution. The solution should then be run into the well through a hose or pipe as it is alternately raised and lowered; this will help mix the solution with the well water. The exterior parts of the pump drop pipe should be washed with the chlorine solution as it is being placed in the well.

To disinfect the water supply system, the pressure system should be started and all faucets on the water supply system should be opened until a strong odor of chlorine is noticed. All faucets should then be closed and if possible, a hose should be attached to one faucet and the water recirculated back into the well for about an hour, thereby washing down the interior wall of the well casing. The chlorine solution should be allowed to remain for at least eight hours and then the water should be run to waste until all traces of chlorine are removed.

To disinfect a spring box, the water should be pumped out with an auxiliary pump and the pump suction pipe and the interior surface of the box should be washed thoroughly with a strong chlorine solution made by mixing 30 mL household laundry bleach with 5 L water. The auxiliary pump should then be stopped to allow the box to refill. The pressure system should then be started and all faucets on the water supply system opened. By means of a hose held at the inlet end of the pump suction pipe, a strong chlorine solution should be continuously fed into the water supply system until a strong odor of chlorine is noticed at each faucet. At this point, the faucets should be turned off, allowing the system to stand idle for at least eight hours. Finally, the water should be run to waste until the chlorine odor disappears.

5. HYDROGEN SULPHIDE AND SULPHATE-REDUCING BACTERIA

The "rotten egg" odor of sulphur water is caused by the presence of hydrogen sulphide gas. Water containing hydrogen sulphide has an objectionable taste; it also promotes corrosion of the plumbing system.

Sulphate-reducing bacteria may also be present in the water. These bacteria change sulphate to hydrogen sulphide and a weak sulphuric acid which makes the water more corrosive. These bacteria do not require oxygen to live. Since hot water contains less oxygen than cold water, the presence of these bacteria can be detected if a hydrogen sulphide odor comes from just the hot water taps.

Two common water treatment methods to correct the hydrogen sulphide problem exist. These methods are: aeration, and chlorination-filtration.

5.1 Aeration

Sulphur water can be treated by spraying it into the air. However, the aeration method does not completely remove the hydrogen sulfide, nor does it lend itself to the treatment of small farm water supplies.

5.2 Chlorination-Filtration

For small water supplies, the chlorination-filtration treatment is the most satisfactory method. A chemical feeder automatically adds chlorine to the water, preferably down the well at the end of the pump drop pipe, or at least before the pump. The chlorine oxidizes the hydrogen sulfide, thus eliminating the bad odor and corrosion problems. In addition, chlorine kills any sulphur bacteria which may be present.

Following chlorination, the water used for most purposes is passed through a sediment filter to remove the precipitated sulphur. To ensure complete precipitation of the sulphur and to allow for variations in hydrogen sulfide which may occur in the water supply, the chemical feeder is usually set to maintain a reasonably high chlorine residual in the treated water.

To remove the objectionable chlorine taste and odor, dechlorination of small quantities of water for drinking and cooking purposes can be accomplished by installing a small activated carbon filter on a tap in the kitchen. A large carbon filter could also be installed after the sediment filter to dechlorinate the whole water supply.

6. CHLORIDE, SULPHATE AND NITRATE

Water with a chloride concentration greater than 250 mg/L is not desirable for domestic use. High chloride concentrations are readily identifiable by a salty taste in the

water. Chloride in itself is not harmful to health, however, high chloride concentrations are nearly always accompanied by high sodium concentrations which may be harmful to those individuals on a low sodium diet or those suffering from high blood pressure, renal or heart diseases.

The maximum desirable sulphate concentration in drinking water is 500 mg/L. At levels above this concentration, sulphate can have a laxative effect; however, regular users adapt to high levels of sulphate in drinking water and problems are usually only experienced by houseguests and new consumers.

The maximum acceptable nitrate concentration in drinking water, 10 mg/L as nitrogen, is based on the consideration of the relationship between infantile methemoglobinemia and the presence of nitrate in drinking water. Methemoglobinemia is a condition whereby the hemoglobin in the blood is altered, interfering with oxygen transfer; the blood is therefore oxygen-starved.

Reverse osmosis can be used to remove chloride, sulphate and nitrate.

6.1 Reverse Osmosis

In a reverse osmosis unit, the water is forced through a semi-permeable membrane leaving the minerals behind.

Small household drinking water units can produce 4 to 12 L/day whereas larger units can supply 200 to 1,200 L water/day (Figure 5). The larger units operate on the same principle as the smaller units except that they include a small pump which increases the pressure inside the reverse osmosis module.

If the raw water is of adequate quality, most domestic units will remove 70-90% of the total dissolved solids and produce a high-quality drinking water. Pretreatment of the raw water may be necessary to ensure:

1. iron or manganese does not exceed 1 mg/L;
2. iron bacteria is controlled;
3. water is soft;
4. chlorine level is closely controlled; and
5. pH is between 5 and 8 (Alberta Agriculture, 1979).

Equipment and installation cost for pretreatment can often exceed the cost of the reverse osmosis unit itself.

Most small units waste 5 to 8 L water for every litre of purified water produced. Larger units (over 400 L/day) are more efficient and waste about 0.5 L for every litre of purified water. Disposing of the waste water can be a problem because the volume may be more than the existing sewage system can handle. Because of the high energy and maintenance costs, reverse osmosis is relatively impractical for any use other than domestic drinking water.

7. TURBIDITY

Ponds which are used as a water supply can be turbid, especially after a heavy rain or rapid snowmelt. Most of the impurities in a pond are close to the bottom. Therefore, to obtain the best water quality, a float suspended intake is recommended because it takes the water from near the surface.

In some new wells the water is turbid or cloudy. This is a result of fine material such as clay, silt, organic matter or other contaminants in suspension. The water can be treated with alum or by filtering. This should only be tried after sufficient pumping has been carried out to clear the water.

7.1 Alum

With a new well, the solution can simply involve the addition of a few teaspoons of alum to coagulate the fine particles. The water then becomes clear as the particles settle to the bottom of the well. Where turbidity remains, it may be necessary to add a filter to remove the fine particles.

7.2 Filters

Diatomite filters and sand and gravel filters are commonly used to remove fine-grained particles. A diatomite filter consists of a filter cake of diatomaceous earth. Water is forced through the filter to remove all turbidity. The filter should be backwashed regularly to maintain its effectiveness.

A sand and gravel filter consists of a tank filled with layers of fine sand, coarse sand, and gravel. It is equipped with valves so that the filter may be backwashed as required to keep it effective and sanitary.

Carbon, cloth, porous stone, and paper filters are also used. These filters are available in cartridges which can be added to the water lines. These cartridges should be replaced periodically.

8. GASOLINE AND OIL

Contamination from the leakage or spillage of petroleum products is an extremely difficult and expensive problem to rectify. This is because by nature petroleum products:

1. are relatively stable and will not readily decompose;

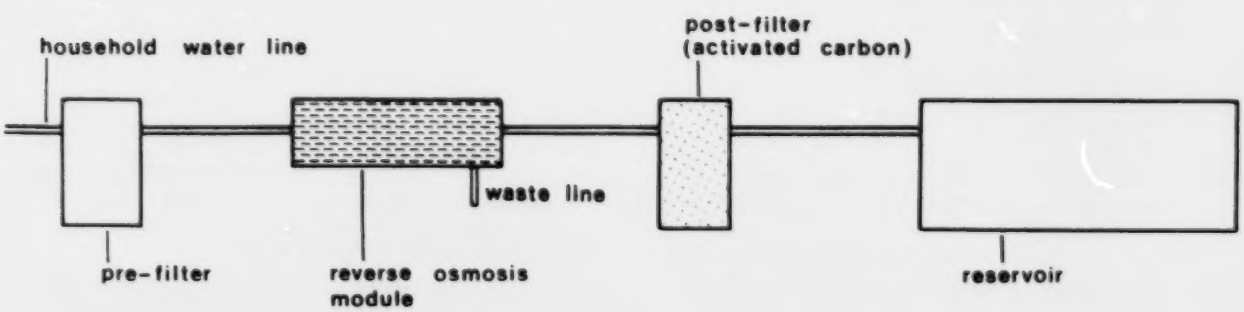


Figure 5. Typical Low-Volume Household Reverse Osmosis Unit

2. are capable of traveling long distances with groundwater;
3. will adhere to soil particles and only be released slowly by the flushing action of infiltrating precipitation; and
4. will release explosive vapors.

When a leak or spill does occur, or a petroleum-like taste or odor is detected in the water supply, it should be reported immediately to the local Ministry of the Environment Regional Office (Appendix IV). Clean-up procedures can be elaborate, such as the excavation and removal of contaminated materials to an approved landfill site, or may simply involve adding an activated carbon filter to the water distribution system to remove the unpleasant taste and odor.

9. GASES (METHANE)

Natural gas escaping into an enclosed well pit or shed has been known to cause explosions and fires. A well containing natural gas should be sealed at the top and fitted with an air vent that releases the gas into the atmosphere at least 2.5 m above ground level. Natural gas in its raw form is often odorless.

Natural gas may also cause water pumps to lose their prime. A gas separator which diverts gas away from the pump intake will protect the pump and improve its operation. The use of aeration and activated carbon filters should also remove any gas which may enter the distribution system.

10. TASTE AND ODOR

There are many causes of bad tastes and odors in water. Treatment for those due to the presence of iron and sulphur have been covered in the sections on iron and hydrogen sulphide.

The objectionable taste and odor caused by the residual chlorine of the chlorination method of treating iron and sulphur can be removed by passing the water through an activated carbon filter. Some other types of tastes and odors may also be removed by chlorination followed by carbon filtration. Some types, such as those from decayed organic matter, may be removed directly by a carbon filter, while others may only be removed by expensive techniques that are not practical for small water supplies. It is best, therefore, to have the water in question checked to determine the effectiveness of a treatment process before equipment is purchased.

10.1 Activated Carbon Filter

An activated carbon filter consists of highly refined charcoal that has a large capacity for adsorbing certain

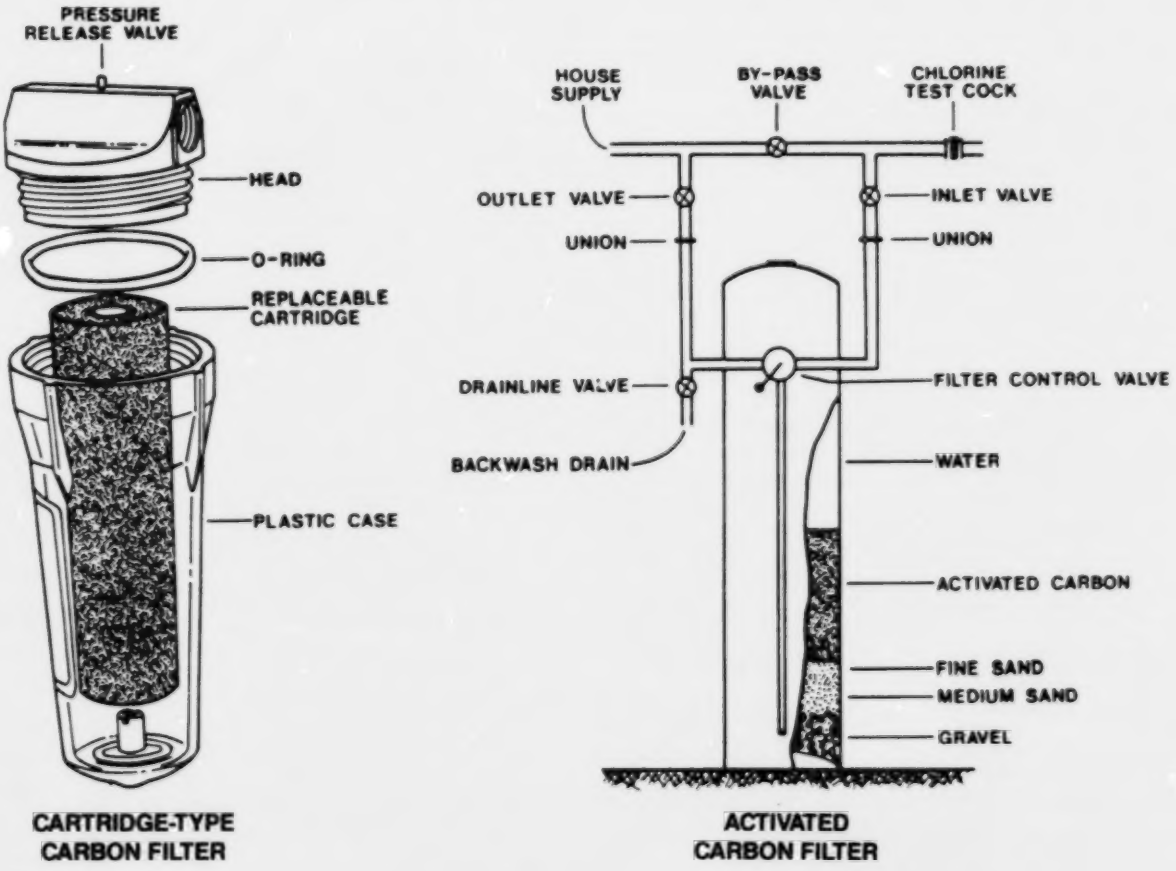


Figure 6. Activated Carbon Devices

types of compounds that cause tastes and odors. Adsorption is the attraction and accumulation of one substance on the surface of another. Activated carbon filters are available as a small replaceable cartridge which fits inside a case or as a large bed of granular carbon contained in a tank similar in appearance to a softener (Figure 6). The cartridge is best suited for use on a single outlet such as a drinking water tap. The tank unit is generally operated in association with a chlorination system. A carbon cartridge costs about $7 and a tank unit ranges in price from $270 to $1,400 (1986 prices).

When the surface of the carbon particles in the filter becomes coated with impurities, the efficiency of the carbon in removing taste and odor is reduced. The filter should be backwashed once a week to remove the collected impurities from the carbon. Under normal conditions, the activated carbon will function for several years. After a lengthy period of operation, the adsorptive power of the carbon is exhausted and since the carbon cannot be regenerated, it must be replaced by new material.

Water containing sediment should be passed through a sediment filter prior to entering a carbon filter, as sediment will rapidly coat the carbon granules, causing premature reduction in its capacity to remove tastes and odors. Activated carbon filters will not remove bacteria or viruses from the water; if the water is contaminated, or is suspected of being contaminated, chlorination will be required.

11. ACIDITY

Water that is acid in character should be neutralized to prevent the corrosion of metal in the plumbing system. Corrosion of steel pipes and fixtures is apparent when red, rusty water comes from the tap, while corrosion of copper pipes will tinge the water a green color, or leave a green stain on porcelain under a leaking faucet. Neutralization of acid water is also important in the treatment of iron where the chlorination technique of precipitation is used.

Acid water can be neutralized by either passing the water through a neutralizer, or by automatically adding soda ash to the water with a chemical feeder.

11.1 Neutralizer

A neutralizer (Figure 7) consists of a bed of marble chips which is gradually consumed in the neutralization process and must be replenished occasionally. The frequency of recharge will depend upon the corrosiveness of the water and the size of the unit installed. Water passing through a neutralizer will increase in hardness.

11.2 Soda Ash

Where soda ash is used for neutralization, it is recommended that the solution be fed through a small tube down the well to the end of the pump drop pipe, or at least into the suction pipe, to protect the pump as well as the rest of the system against corrosion. Chemical feeders which are used to add soda ash must be constructed of material that is resistant to attack by this strongly alkaline solution.

12. PESTICIDES

Pesticides are chemicals. Included in this group are: insecticides, herbicides, fungicides, nematocides, and rodenticides. Pesticides can appear in surface water as a result of adsorption to soil particles in runoff water, adsorption to wind-blown soil particles, direct application to control biting flies or aquatic weeds, spray drift, spills in or near water bodies, or careless disposal of waste pesticides or containers. Groundwater may become contaminated by backsiphoning of a spray tank during filling and mixing with water or by leaching of pesticides through the soil to tile drains and shallow wells.

Care should be taken to avoid contamination of any well or surface water supply. In fact, farm families should not use the same well to draw spray water as they use for domestic supplies.

Three methods are available to treat water contaminated by pesticides. They are boiling, reverse osmosis, and activated carbon. However, where contamination is severe, a new water supply may have to be considered.

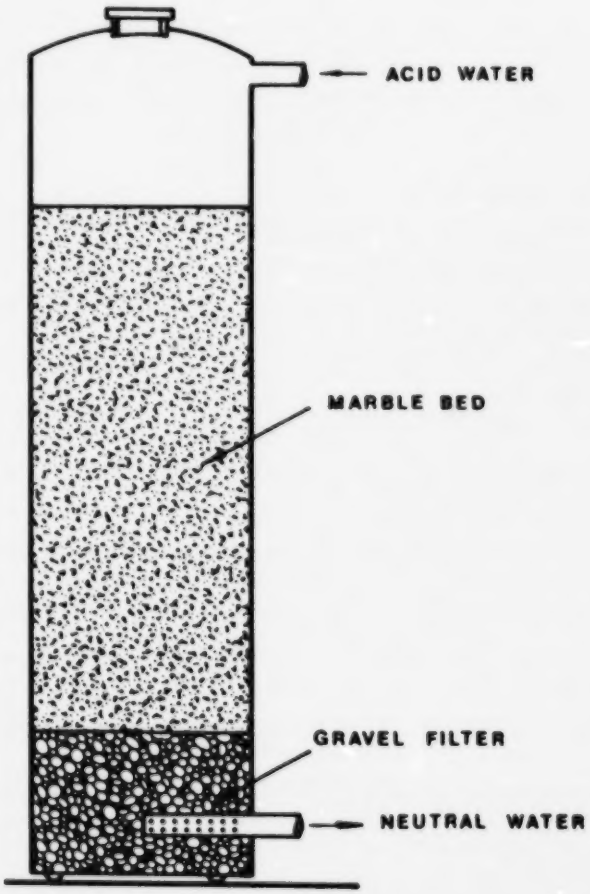


Figure 7. Neutralizer

12.1 Boiling

If contamination is a result of volatile organic chemicals, the water can be boiled as an immediate step until other more effective methods can be installed. The boiling point of the contaminant must be below that of water. A potential health risk may be the inhalation of the vapors.

12.2 Reverse Osmosis

Reverse osmosis has the potential to remove some pesticides from water, depending on the membrane used. Cellulose acetate membranes have not been known to be

effective, except for high molecular weight organic contaminants. Non-cellulosic membranes are more effective.

12.3 Activated Carbon

Adsorption by activated carbon is the most efficient and cost effective method for removal of pesticides. It must be noted that activated carbon does not absorb all contaminants equally. The absorption capacity of activated carbon depends on the particular contaminant, the composition of the mix in the feedwater, the weight of the granular activated carbon, and the residence time in the filter.

BIBLIOGRAPHY

Alberta Agriculture, 1977. *Activated Carbon Filter.* Agri-fax, Agdex 716(D43).

Alberta Agriculture, 1979. *Alternatives for Iron Removal.* Agri-fax, Agdex 716(D11).

Alberta Agriculture, 1979. *Reverse Osmosis.* Agri-fax, Agdex 716(D36).

Alberta Agriculture, 1980. *Iron Removal by Chlorination and Filtration.* Agri-fax, Agdex 716(D34).

Alberta Agriculture, 1983. *Shock Chlorination and Control of Iron Bacteria.* Agri-fax, Agdex 716(D12).

Blom, T., B. Straver, W. Brown, J. Hughes, 1987. *Water Quality for Greenhouse Crops.* OMAF Factsheet, Agdex 290/15.

Cole, L., 1985. *Update on Methods for the Removal of Iron, Manganese, Hydrogen Sulphide, and pH Control.* Presented at the Fourth Domestic Water Quality Symposium, Water Quality Association and American Society of Agricultural Engineers, "Technical Papers".

Fay, D.M., 1985. *Planning a New Water Well.* OMAF Factsheet, Agdex 716.

Frank, R., 1986. *Pesticide Contamination of Farm Water Supplies.* OMAF Factsheet, Agdex 607.

Frank, R., 1987. *Guide to Handling and Applying Herbicide to Protect Water Supplies and Reduce Personal Exposure.* OMAF Factsheet, Agdex 607.

Funk, G., W.A. McClenaghan and C. Holland, 1980. *Water Wells and Groundwater Supplies in Ontario.* Ontario Ministry of the Environment.

Hore, F.R., 1973. *Farm Water Supply.* OMAF Publication 476.

Irwin, R.W., 1987. *Water Quality for House and Barn.* OMAF Factsheet, Agdex 716.

Irwin, R.W. and W.J. Hicks, 1979. *Farm Water Use.* University of Guelph, Guelph, Ontario.

Mancl, K.M., *Iron Removal.* Pennsylvania State University and the U.S. Department of Agriculture, Agricultural Engineering Factsheet.

National Academy of Sciences, 1974. *Nutrients and Toxic Substances in Water for Livestock and Poultry.*

Ontario Ministry of the Environment. *Information on the Use of Home Water Treatment Devices.*

Ontario Ministry of the Environment, 1983. *Ontario Drinking Water Objectives.*

Ontario Ministry of the Environment, 1984. *Water Management, Goals, Policies, Objectives and Implementation Procedures of the Ministry of the Environment.*

Regunathan, P. and W.H. Bowman, 1985. *A Comparison of Point-of-Use Disinfection Methods.* Presented at the Fourth Domestic Water Quality Symposium, Water Quality Association and American Society of Agricultural Engineers, "Technical Papers".

Rozelle, L.T., 1985. *Point-of-Use Treatment of Organics.* Presented at the Fourth Domestic Water Quality Symposium, Water Quality Association and American Society of Agricultural Engineers, "Technical Papers".

Smith, L.J., *Better Water, Better Milk.* Canadian Water Quality Association.

Smith, L.J., *Better Water for the Farm.* Canadian Water Quality Association.

APPENDICES

APPENDIX I
WATER QUALITY GUIDELINES

The Ministry of the Environment has established objectives and criteria for water quality based on its intended use (Ontario Ministry of the Environment, 1983, 1984). A summary of these objectives is presented in the following table. There is no legal enforcement of these guidelines; they are neither a requirement nor a right. They simply provide an indication of the best current estimates of minimum quality of water required for each of the uses. It is strongly recommended, however, that these guidelines be followed to prevent health problems and losses in productivity.

WATER QUALITY GUIDELINES FOR PUBLIC HEALTH, LIVESTOCK WATERING, IRRIGATION, AND AESTHETIC CONSIDERATIONS

Parameters	Public Health Parameters MAC	Livestock Watering	Irrigation for Continuous Use on All Soil	Aesthetic Parameters MDC
Aluminum		5.0	5.0	
Arsenic	0.05	0.2	0.10	
Bacteria				
Total Coliform	< 5/100 mL		1000/100 mL	
Fecal Coliform	0		100/100 mL	
Barium	1.0			
Beryllium			0.10	
Boron	5.0	5.0	0.75	
Cadmium	0.005	0.05	0.010	
Chloride				250
Chromium	0.05	1.0	0.10	
Cobalt		1.0	0.050	
Color				5 TCU
Copper		0.5	0.20	1.0
Cyanide (Free)	0.2			
Fluoride	2.4	2.0	1.0	
Hardness				500
Iron			5.0	0.3
Lead	0.05	0.1	5.0	
Lithium			2.5	
Manganese			0.20	0.05
Mercury	0.001	0.01		
Methane				3 L/m³
Molybdenum			0.010	
Nickel		1.0	0.20	
Nitrate (as N)	10.0*	100.0		
Nitrite (as N)	1.0	10.0		
Nitrilotriacetic Acid (NTA)	0.05			
Odor				Inoffensive
Organic Nitrogen				0.15**
PESTICIDES				
Aldrin		0.001		
Aldrin + Dieldrin	0.0007			
Carbamate and organophosphorus pesticides		0.1		
Carbaryl	0.07			
Chlordane	0.007	0.003		
DDT	0.03***	0.05		
Diazinon	0.014			
Dieldrin		0.001		
Endrin	0.0002	0.0005		
Heptachlor		0.0001		
Heptachlor Epoxide		0.0001		

(continued on page 20)

WATER QUALITY GUIDELINES FOR PUBLIC HEALTH, LIVESTOCK WATERING, IRRIGATION, AND AESTHETIC CONSIDERATIONS (cont'd.)

Parameters	Public Health Parameters MAC	Livestock Watering	Irrigation for Continuous Use on All Soil	Aesthetic Parameters MDC
Heptachlor + Heptachlor Epoxide	0.003			
Lindane	0.004	0.005		
Methoxychlor	0.1	1.0		
Methyl Parathion	0.007***			
Parathion	0.035			
Toxaphene	0.005	0.005		
2,4-D	0.1			
2,4,5-TP	0.01			
pH				6.5-8.5
Phenols				0.002
Salinity (total soluble salts)		3000		
Selenium	0.01	0.05	0.020	
Silver	0.05			
Sulphate				500
Sulphide				Inoffensive
Taste				Inoffensive
Temperature				15°C
Total Dissolved Solids				500
Total Organic Carbon				5.0
Toxic Algae		no heavy growth		
Trihalomethanes	0.35			
Turbidity	1 FTU			
Vanadium		0.1	0.1	
Zinc		25.0	2.0	5.0

Note Units are in mg/L unless otherwise stated.

FTU Formazin Turbidity Unit
MAC Maximum Acceptable Concentration
MDU Minimum Desirable Concentration
TCU True Color Units

* *Where both nitrate and nitrite are present, the total nitrate plus nitrite-nitrogen should not exceed 10 mg/L.*

** *Total Kjeldahl nitrogen minus ammonia nitrogen.*

*** *When more than one of these pesticides is present, the "total pesticides" shall not exceed the sum of their MAC's or 0.1 mg/L, whichever is the lesser.*

Source: Ontario Ministry of the Environment, 1983.
Ontario Ministry of the Environment, 1984.

APPENDIX II
THE INFLUENCE OF WATER QUALITY ON LIVESTOCK HEALTH AND PERFORMANCE

There is little definitive research on the influence of individual water quality parameters on livestock performance. Researchers do not agree on the concentrations at which health and performance of the animals are affected. Part of the difficulty in obtaining consistent results may be that the effect of water quality is generally not a major factor in the total nutrient intake and management of the animal.

As a consequence, provided that the water is free of disease agents and the animals are not showing obvious signs of toxicity, it is likely more cost-effective to adjust other management factors than it is to treat the water.

Despite the above qualifications, the following table provides some additional guidance.

EFFECT OF SALINE WATERS ON LIVESTOCK AND POULTRY

Concentration (mg/L)	Effect
< 1000	Low level of salinity; presents no serious burden to any class of livestock or poultry.
1000-2999	Satisfactory for all classes of livestock and poultry; may cause temporary mild diarrhea in livestock not accustomed to it, or watery droppings in poultry at higher levels; does not effect health or performance.
3000-4999	Satisfactory for livestock; may cause temporary diarrhea or be refused by animals not accustomed to it; poor water for poultry, causing watery feces; increased mortality and decreased growth at higher levels, especially in turkeys.
5000-6999	Reasonable safety for dairy and beef cattle, sheep, swine and horses; avoid use for pregnant or lactating animals; not acceptable for poultry as it causes decreased growth and production, or increased mortality.
7000-10,000	Unfit for poultry and swine; a risk if used for pregnant or lactating cows, horses, sheep, the young of these species, or animals subjected to heavy heat stress or water loss; use should be avoided, although older ruminants, horses, poultry and swine may subsist for long periods of time under conditions of low stress.
> 10,000	Risks are great; cannot be recommended for use under any condition.

Source: National Academy of Sciences, 1974.

APPENDIX III
PARAMETERS TO CONSIDER IN ASSESSING IRRIGATION WATER QUALITY

In assessing irrigation water quality, the following parameters should be considered.

1. The total salt content is the single most important criterion for evaluating irrigation water quality. However, all crop tolerance data are based on the salinity of the soil solution in the root zone, and these data are applicable to specific crops. Although criteria are not included here, waters with a salt content of less than 700 to 800 mg/L are not expected to create serious problems. An indication of total salt content can also be obtained by measuring the Electrical Conductivity (EC) of the water. Generally, waters with EC values of less than 1 mmhos/cm can be considered safe for all conditions. Water with EC values of 1-2 mmhos/cm could cause problems; in this case, decisions about irrigation should be based on the advice of irrigation specialists.
2. As a component of total salinity, sodium in irrigation water may be a problem in the soil solution. The sodium adsorption ratio (SAR) is an expression of the amount of sodium adsorbed on the soil:

$$SAR = Na^{+}\sqrt{\quad (Ca^{++} + Mg^{++})/2}$$

   where the cations are expressed in meq/L (milliequivalent per litre). SAR values of less than 4 will not create toxicity problems for foliar absorption. For the less sensitive crops, values of up to 6 or 7 can be used. However, higher SAR values may cause a reduction in soil permeability and should be avoided.
3. Chlorides in irrigation waters are not generally toxic to crops. Certain fruit crops are, however, sensitive to chlorides; and foliar absorption of chlorides can be an important consideration in sprinkler irrigation. Permissible chloride concentrations depend upon the type of crop, environmental conditions and management practices. A single value cannot be recommended because detrimental effects from salinity ordinarily deter crop growth first.
4. High bicarbonate water may induce chlorosis by making iron unavailable to plants. Although concentrations of 10 to 20 meq/L of bicarbonate can cause chlorosis in some plants, it is of little concern in the field where precipitation of calcium carbonate minimizes this hazard. Specific recommendations for bicarbonates cannot be given without consideration of other soil and water constituents.
5. The temperature of irrigation water has a direct and indirect effect on plant growth. Both occur when physiological functions of plants are impaired by excessively high or excessively low temperatures. The exact water temperature at which growth is severely restricted depends on the method of water application, the atmospheric conditions at the time of application, the frequency of application, and the plant species. All plant species have a temperature range in which they develop best. These temperature limits vary with each plant species. Present literature does not provide adequate data to establish specific temperature recommendations for irrigation waters.
6. In general, the effect of acidity and alkalinity on soils and plant growth is indirect and no specific pH values can be recommended. However, water with pH values in the range of 4.5 to 9.0 should be usable provided that care is taken to detect the development of harmful indirect effects.
7. There is a lack of experimental evidence concerning the long-term accumulation and availability of radionuclides in irrigated soils. To provide an adequate margin of safety, it is recommended that the Ontario Drinking Water Objectives be used as a guideline for irrigation water (Ontario Ministry of the Environment, 1983).
8. Irrigation water used on crops which may be eaten raw or with little processing and which are irrigated by a spray or sprinkler mechanism must be of the best microbiological quality possible, in order to protect the consumer from the transmission of disease. Irrigation water should meet the quality objectives for swimming and bathing uses (Ontario Ministry of the Environment, 1984). Such waters should be protected against the infiltration of barn yard wastes and other sources of human and/or animal fecal material.
9. Pesticides: When present in irrigation water, pesticides can leave unacceptable residues on crops, or be injurious to crop growth. Of all the various pesticide residues, herbicides are the most injurious to crop growth. Insecticides, fungicides, nematocides and other pesticides, excluding herbicides, are generally not phytotoxic to field-grown crops in concentrations as low as the drinking water criteria. However, they could leave undesirable residues on a harvested crop. Some fungicides such as chlorinated phenols and dithiocarbamate, if present in water, can damage indoor-grown mushrooms.

When assessing irrigation water for possible effects of herbicide residues on crops, one must take into account the following factors:

- toxicity of the herbicide and its concentration;
- the susceptibility of the crop being irrigated and the stage of growth at which it is being watered;
- the frequency and the volume of irrigating water used;
- the weather conditions; and
- the soil type and pH.

At the present time, experience shows that two major types of herbicides are of primary concern: the "hormone-type" herbicides, and the nitrogen-containing triazines. Injury has been observed to seedling crops when both types of herbicides are used at a concentration of 0.5 ug/L. Therefore, irrigation water residues of these pesticides should be below this threshold limit to avoid crop damage.

The hormone-type herbicides include:		The triazines include:
2,4-D	fenoprop	atrazine
2,4,5-T	MCPB	simazine
MCPA	dicamba	cyanazine
picloram	dichlorprop	metribuzin
2,4-DB	mecoprop	

In addition to the above important parameters, trace elements (in concentrations less than a few mg/L, or usually less than 100 ug/L) may cause reduced plant growth. The recommended maximum concentrations of trace elements in irrigation water are shown in Appendix I.

Source: Ontario Ministry of the Environment, 1984.

APPENDIX IV

LIST OF CONTACTS

ONTARIO MINISTRY OF AGRICULTURE AND FOOD - COUNTY AND DISTRICT OFFICES

County/District	Telephone No.	Address
ALGOMA	705-253-1161	Heritage Corner, 341 Trunk Rd., Sault Ste Marie P6A 3S9
BRANT	519-759-4190	515 Park Rd. N., Unit 7, Brantford N3S 7K8
BRUCE	519-881-3301	Box 1330, 10 Jackson St., Walkerton N0G 2V0
CARLETON	613-828-9167	26 Thorncliff Pl., Nepean K2H 6L2
COCHRANE N.	705-335-5828	Experimental Farm, Hwy. 11 West, Kapuskasing P5N 2X9
COCHRANE S.	705-273-2509	Box 608, 4th Ave., Matheson P0K 1N0
DUFFERIN	519-941-3830	R.R. #4, Mono Plaza, Orangeville L9W 2Z1
DUNDAS	613-774-2313	Box 488, 457 Main St., Winchester K0C 2K0
DURHAM EAST	416-623-3348	234 King St. E., 2nd Flr., Bowmanville L1C 1P5
DURHAM WEST	416-852-3328	Box 309, 16 Bascom St., Uxbridge L0C 1K0
ELGIN	519-631-4700	Box 2027, St. Thomas N5P 3X1
ESSEX	519-776-7361	46 Fox St., Essex N8M 2S2
FRONTENAC	613-545-4360	Box 651, 1055 Princess St., Kingston K7L 4X1
GLENGARRY	613-525-1046	Box 579, St. George St. E., Alexandria K0C 1A0
GRENVILLE	613-258-8295	Box 2004, Prov. Bldg., Kemptville K0G 1J0
GREY	519-986-2040	181 Toronto St. S., Markdale N0C 1H0
HALDIMAND	416-772-3381	Box 129, Cayuga N0A 1E0
HALTON	416-878-2314	17 Wilson Dr., Unit 12, Milton L9T 3J7
HASTINGS	613-395-3393	Box 340, Stirling K0K 3E0
HURON	519-482-3428	Box 159, 20 King St., Clinton N0M 1L0
KENORA	807-223-2415	Ont. Gov't. Bldg., Box 3000, Dryden P8N 3B3
KENT	519-354-2150	Box 726, 435 Grand Ave. W., Chatham N7M 5L1
LAMBTON	519-882-0180	Box 730, 360 Hwy. 21, Petrolia N0N 1R0
LANARK	613-267-1063	10 Sunset Blvd., Perth K7H 2Y2
LEEDS	613-342-2124	Box 635, 333 California Ave., Unit 16, Brockville K6V 5V8
LENNOX & ADD.	613-354-3371	41 Dundas St. W., Napanee K7R 1Z5
MANITOULIN	705-282-2043	Box 328, Gore Bay P0P 1H0
MIDDLESEX	519-434-6811	50 King St., London N6A 2P2
MUSKOKA & P.S.	705-789-8886	Box 130, 8 Centre St. N., Huntsville P0A 1K0
NIAGARA N.	416-562-4142	Advisory Services Bldg., Vineland Station L0R 2E0
NIAGARA S.	416-732-7552	726 Canboro Rd., Fenwick L0S 1C0
NIPISSING	705-474-3050	222 McIntyre St. W., North Bay P1B 2Y8
NORFOLK	519-426-7120	Box 587, Simcoe N3Y 4N5
NORTHUMBERLAND	613-475-1630	Box 8200, 95 Dundas St., Brighton K0K 1H0
OXFORD	519-537-6621	Box 666, Hwy. 59 N., Woodstock N4S 7Z5
PEEL	416-451-5474	35 Van Kirk Dr., Unit 9, Brampton L7A 1A5
PERTH	519-271-0280	413 Hibernia St., Stratford N5A 5W2
PETERBOROUGH	705-745-2403	55 George St. N., Peterborough K9J 3G2

County/District	Telephone No.	Address
PRESCOTT	613-673-5115	Box 110, Plantagenet K0B 1L0
PRINCE EDWARD	613-476-3224	Box 470, Picton K0K 2T0
RAINY RIVER	807-482-2310	Front St., Emo P0W 1E0
RENFREW	613-432-4841	315 Raglan St. S., Renfrew K7V 1R6
RUSSELL	613-443-3391	735 Rue Notre Dame, Box 540, Embrun K0A 1W0
SIMCOE N.	705-322-2231	Box 340, 144 Yonge St. S., Elmvale L0L 1P0
SIMCOE S.	705-435-5521	Box 370, Alliston L0M 1A0
STORMONT	613-346-2143	Box 97, Centennial Dr., Avonmore K0C 1C0
SUDBURY	705-566-1630	1899 LaSalle Blvd., Sudbury P3A 2A3
THUNDER BAY	807-475-1631	Ont. Gov't. Bldg., 435 James St. S., Thunder Bay P7E 6E3
TIMISKAMING	705-647-6701	Box "G", Hwy. 11B, New Liskeard P0J 1P0
VICTORIA-HALIBURTON	705-324-6125	322 Kent St. W., Lindsay K9V 2Z9
WATERLOO	519-884-5390	279 Weber St. N., Waterloo N2J 3H8
WELLINGTON	519-846-0941	Wellington Place, R.R. #1, Fergus N1M 2W3
WENTWORTH	416-527-2995	R.R. #1, 617 Hwy. 53 E., Ancaster L9G 3K9
YORK	416-895-4519	1110 Stellar Dr., Unit 102, Newmarket L3Y 7B7

ONTARIO MINISTRY OF HEALTH - REGIONAL LABORATORIES

Public Health Laboratory
Ontario Ministry of Health
P.O. Box 2100
HAMILTON, Ontario
L8N 3R5 (416) 385-5379

Public Health Laboratory
Ontario Ministry of Health
P.O. Box 240
KINGSTON, Ontario
K7L 4V8 (613) 547-2292

Public Health Laboratory
Ontario Ministry of Health
P.O. Box 5704, Terminal "A"
LONDON, Ontario
N6A 4L6 (519) 455-9310

Public Health Laboratory
Ontario Ministry of Health
P.O. Box 600
ORILLIA, Ontario
L3V 6K5 (705) 325-7449

Public Health Laboratory
Ontario Ministry of Health
P.O. Box 6301, Station "J"
OTTAWA, Ontario
K2A 1S8 (613) 828-2442

Public Health Laboratory
Ontario Ministry of Health
P.O. Box 700
PALMERSTON, Ontario
N0G 2P0 (519) 343-3102

Central Laboratory
Ontario Ministry of Health
Box 9000, Terminal "A"
TORONTO, Ontario
M5W 1R5

Public Health Laboratory
Ontario Ministry of Health
P.O. Box 265
PETERBOROUGH, Ontario
K9J 6Y8 (705) 743-6811

Public Health Laboratory
Ontario Ministry of Health
P.O. Box 220
SAULT STE MARIE, Ontario
P6A 5L6 (705) 254-7132

Public Health Laboratory
Ontario Ministry of Health
1300 Paris Crescent
SUDBURY, Ontario
P3E 3A3 (705) 522-2640

Public Health Laboratory
Ontario Ministry of Health
P.O. Box 1100, Station "F"
THUNDER BAY, Ontario
P7C 4X9 (809) 622-6449

Public Health Laboratory
Ontario Ministry of Health
67 Wilson Avenue
TIMMINS, Ontario
P4N 2S5 (705) 264-9571

Public Health Laboratory
Ontario Ministry of Health
P.O. Box 1616
WINDSOR, Ontario
N9A 6S2 (519) 969-4341

ONTARIO MINISTRY OF THE ENVIRONMENT - REGIONAL OFFICES

Central Region

Toronto Regional Office
4th Floor
7 Overlea Blvd.
TORONTO, Ontario
M4H 1A8 (416) 424-3000

Northeastern Region

Sudbury Regional Office
11th Floor
199 Larch Street
SUDBURY, Ontario
P3E 5P9 (705) 675-4501

Northwestern Region

Thunder Bay Regional Office
P.O. Box 5000
3rd Floor
435 James Street South
THUNDER BAY, Ontario
P7C 5G6 (807) 475-1205

Southeastern Region

Kingston Regional Office
P.O. Box 820
133 Dalton Avenue
KINGSTON, Ontario
K7L 4X6 (613) 549-4000

Southwestern Region

London Regional Office
985 Adelaide Street South
LONDON, Ontario
N7E 1V3 (519) 681-3600

West Central Region

Hamilton Regional Office
P.O. Box 2112
12th Floor
119 King Street West
HAMILTON, Ontario
L8N 3Z9 (416) 521-7640

NOTES

N-10-89-2M
© QUEEN'S PRINTER FOR ONTARIO, 1989
ISBN 0-7729-6219-7